BELLCOMM, INC.

SUBJECT: Proposed Application of the Boeing Operations Analysis at MSFC to the Question of Implementing Extended Pad Hold Capability for Initial Lunar Missions - Case 330

DATE: February 16, 1967

FROM: C. H. Eley III

ABSTRACT

This paper presents an application of the MSFC/Boeing operations analysis as a readily available tool for evaluating the effects on the launch vehicle of a pad hold spanning two lunar launch windows. Thus, substantial information can be available to the Apollo program management for use upon which to base a decision should the desirability for implementing an extended hold capability increase.

A brief summary of the discussion is as follows:

a. A question as to whether a pad hold spanning two lunar launch windows could be used (as an alternate to recycling) was brought up by Dr. von Braun at the Management Council Review in November, 1966. A subsequent report stated a hold capability over 12 hours is not currently possible due to insufficient cryogenic storage facilities for LOX, LH_2 and LN_2.

b. As planning for the first lunar mission develops, an extended pad hold capability may become more attractive to alleviate operational constraints. Should this occur, Apollo program management may want to re-evaluate whether such a capability should be implemented.

c. The Boeing operations analysis--for MSFC--utilizes a large computer simulation model to analyze assembly, checkout and launch operations of the launch vehicle. Analysis shows that a built-in hold (up to two hours) after completion of launch vehicle cryogenics loading reduces launch availability. In regard to (b) above, the effects of a 24 hour extended pad hold would be similar to those encountered in, say, a built-in hold of the same duration. Hence, the Boeing model is a readily available tool for evaluating an extended pad hold for lunar mission operations.

[redacted]

(NASA-CR-153716) PROPOSED APPLICATION OF THE BOEING OPERATIONS ANALYSIS TO MSFC TO THE QUESTION OF IMPLEMENTING EXTENDED PAD HOLD CAPABILITY FOR INITIAL LUNAR MISSIONS (Bellcomm, Inc.) 17 p

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BELLCOMM, INC.

SUBJECT: Proposed Application of the Boeing Operations Analysis at MSFC to the Question of Implementing Extended Pad Hold Capability for Initial Lunar Missions - Case 330

DATE: February 16, 1967

FROM: C. H. Eley III

~~N67-36041~~
18 Pg.
code 11
NASA-CR-83484

MEMORANDUM FOR FILE

1. INTRODUCTION

Recently, Apollo/Saturn V mission operations planning for the first lunar mission has developed to include the launch opportunity characteristics and recycle requirements.

At the Management Council Review in November, 1966, a comment by Dr. von Braun concerned the feasibility of utilizing an extended pad hold between two launch windows (24 hours) as an alternate to recycling the space vehicle which requires at least 44 hours (for a scrub occurring after launch vehicle cryogenics loading). An action item was subsequently generated for the centers to review the system's capability to support a pad hold spanning two launch windows. The report to the Management Council Review in January, 1967, stated that a hold capability over 12 hours is not currently possible due to insufficient cryogenic storage facilities for LOX, LH_2 and LN_2.* This is in addition to an inability to replenish consumables aboard the spacecraft while the MSS is away from the pad. The impression was left, however, that no major space vehicle problems existed (other than replenishing consumables) which constrained an extended hold capability. This has not definitely been established, and it is possible that in the near future the Apollo program management may want to re-evaluate whether an extended hold capability should be implemented.

The purpose of this memorandum is to (1) briefly examine the question of an extended hold, (2) explain the potential role of the MSFC/Boeing operations analysis, and (3) show its applicability to examine the constraints associated with implementing an extended hold (for the launch vehicle).

In conjunction with (3) above, the author has already suggested such a step to MSFC which was favorably received. Mr. L. Sinko, R-P&VE-VOR, at MSFC, states that Boeing is now

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*"System Hold and Recycle Capability for the First Lunar Landing Mission - Part II," Case 310, Bellcomm Memorandum For File (Draft) dated February, 1967, by R. L. Wagner.

[redacted]

starting--on a limited scale--to examine extended pad holds with the simulation model they have developed as part of their operations analysis.

2. DESIRABILITY OF AN EXTENDED HOLD CAPABILITY

It is not the purpose of this paper to advocate development of an extended pad hold capability at LC-39. From the standpoint of flight crew turn-around, the desirability of utilizing an extended hold between two lunar launch windows is highly questionable. There are, however, a number of points concerning the first lunar mission which may require a re-evaluation of whether to implement such a capability for the purpose of increased flexibility. Two considerations in this respect are:

a. Analysis of current lunar orbiter data indicates landing sites may not be equitably spread across the Apollo Block on the lunar surface. Hence, mission planning may not always be able to choose from among a combination of launch days within the launch opportunity to best accommodate launch operations.

b. The space vehicle is currently limited to a lunar mission launch during one of two successive monthly launch opportunities (once hypergolic propellants are loaded). Should the first launch opportunity be missed due to some malfunction, it may become desirable to plan for more than three actual launch attempts the second month. In regard to (a) above, some of the available sites for this planning may lie too near one another to accommodate a recycle operation. Hence, an extended hold capability would become more attractive.

3. POTENTIAL ROLE OF THE MSFC/BOEING OPERATIONS ANALYSIS

a. General

In the latter part of 1965, Boeing--under contract to MSFC--began an operations analysis on the launch vehicle and MSFC supplied GSE. In this, Boeing utilizes a large computer simulation model to analyze assembly, checkout and launch operations of the launch vehicle. (A description of the Boeing model is included as Appendix A.) A major output of the Boeing model is termed "Launch Vehicle Availability" (LVA), e.g., probability of launch during a lunar window. Other outputs identify major factors contributing to "non-availability." This has been a continuing effort which MSFC has utilized to flag those areas of greatest unreliability in the launch vehicle (and MSFC-GSE) for corrective action.

b. Application to Question of Extended Hold

In a previous memorandum,* the author proposed a built-in hold be added to the countdown for a lunar mission to improve operational flexibility. In response to this, Boeing examined--through their model--the effects of a built-in hold on launch vehicle availability. Surprisingly, they found that with cryogencis on board, the mean time to repair is so long that the effect of a programmed hold is not advantageous.

As shown in Figure I, which is included from an MSFC Quarterly Review,** a programmed hold after completion of launch vehicle cryogenics loading reduces the launch availability. Note also, the availability is further reduced as the length of the built-in hold is increased. The small percentage-decrease in launch vehicle availability for a two hour built-in hold is unimportant here. The main point is that the effects of a 24-hour extended hold would be very similar to those encountered in, say, a built-in hold of the same duration. Hence, the Boeing model is a readily available tool for evaluating extended pad hold capability for lunar mission operations. Although the percentage decrease in launch vehicle availability may become significant for a long hold, the main advantage to be gained from the Boeing model is the quick identification of major factors contributing to non-availability. Thus, more substantial information can be available upon which to base a decision should the desirability of an extended pad hold increase.

In proposing the Boeing operation analysis be used to study the question of an extended hold, it must be pointed out the analysis is launch vehicle oriented and impacts from the spacecraft and KSC-GSE would have to be carefully evaluated. Unfortunately, a similar analysis on the spacecraft does not exist. However, it would be possible to factor in data on KSC-GSE and even weather conditions if so desired.

C. H. Eley III

2032-CHE-gmp

Attachments
- Figure 1
- Appendix A

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*"Proposed Improvement in Countdown Flexibility for the Apollo/Saturn V Lunar Landing Mission," Case 140, Bellcomm Memorandum For File dated September 30, 1965, by C. H. Eley III.

**"Saturn V Quarterly Technical Project Review - Systems Engineering & Integration Program for the Third Quarter - Fiscal Year 1966," MSFC, dated April 26, 1966.

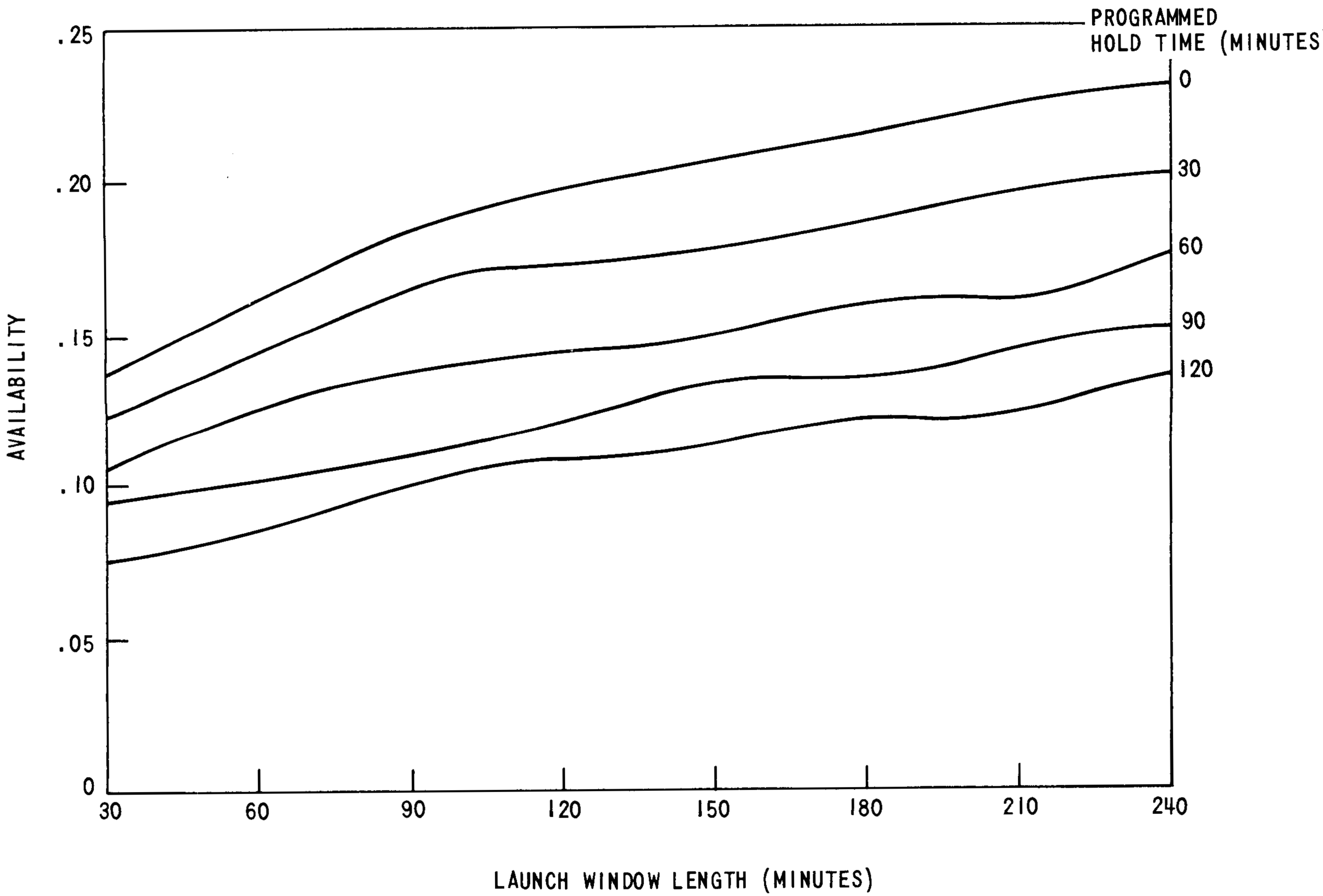

FIGURE 1 IMPACT OF PROGRAMMED-HOLD ON LAUNCH VEHICLE AVAILABILITY
(HOLD PLACED AT START OF AUTOMATIC COUNTDOWN)

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AIAA Paper No. 67-205, presented at the AIAA Fifth Aerospace Sciences Meeting, Ground Testing and Simulation Session on January 23-25, 1967.

APPENDIX A and

IMPLEMENTATION OF ADVANCED SIMULATION TECHNIQUES FOR PREDICTING THE SATURN V LAUNCH VEHICLE SYSTEM BEHAVIOR

J. E. Snyder, Saturn V Operations Analysis Supervisor; E. R. Bennich, Launch Sequence Optimization Supervisor; and Y. H. Lindsey, Systems Simulation Supervisor, The Boeing Company, Huntsville, Alabama.

ABSTRACT

The application of a large digital computer simulation model in analyzing the assembly, checkout, and launch of the Saturn V Launch Vehicle is described in this article. The objective of the analysis is to develop a detailed understanding of the behavior of the Saturn V System in the prelaunch phase, to evaluate the system's effectiveness, and to formulate recommendations for system improvement. The simulation model contains over 500 major events, divided into over 20,000 subevents, each of which must be accomplished to prepare the Saturn V for launch.

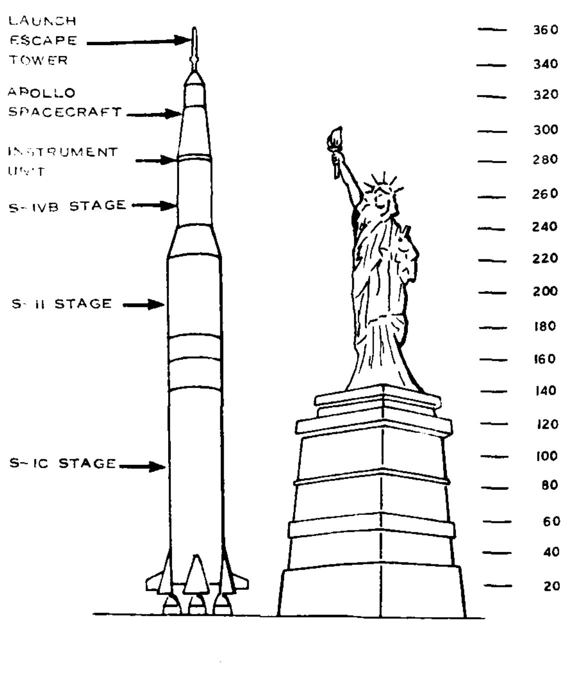
The model was designed using several computer languages (Fortran, Cobol and GPSS) and is used to identify potential problems which are analyzed to determine what elements of the system require improvement. Proposed changes are then programmed into the model to measure the effect of changed parameters such as equipment reliability, equipment maintainability, operational and maintenance concepts, and sequence changes. These are further evaluated with constraints such as cost and safety to determine the feasibility of the proposed changes. Specific recommendations are documented in trade studies and forwarded to the customer for an implementation decision. A high degree of success has been achieved.

INTRODUCTION

Teams from the George C. Marshall Space Flight Center (MSFC) and industrial contractors are developing the free world's largest booster for launching a payload into space - the Saturn V Launch Vehicle (Fig 1). It is being developed initially for Project Apollo, America's manned lunar landing program. The Saturn V will lift a three-man Apollo Spacecraft from Launch Complex 39, Kennedy Space Center (KSC), Merritt Island, Fla., into an earth parking orbit, then inject it into a lunar transfer trajectory (Fig 2). After injection, the Saturn V mission ends and the Apollo Spacecraft accomplishes the remainder of the mission. This consists of lunar orbit, Lunar Excursion Model (LEM) separation and descent with two men to the surface of the moon, LEM ascent to orbit, rendezvous, crew transfer back to Apollo capsule and return to earth.

In support of the MSFC role in this program, an operations analysis is being conducted to perfect the Saturn V System in the prelaunch phase. This paper provides a description of the analysis, with emphasis on detailed simulation of the performance of the Saturn V System during the assembly, checkout and launch activ-

SATURN V LAUNCH VEHICLE



CHARACTERISTICS

LAUNCH VEHICLE	
LENGTH	281 FT
LENGTH VEHICLE, SPACECRAFT, LES	365 FT
WEIGHT AT LIFTOFF	6,200,000 LBS
PAYLOAD CAPABILITY APPROXIMATE	
TRANSLUNAR TRAJECTORY	95,000 LBS
EARTH ORBIT	250,000 LBS
STAGES	
S-IC	
SIZE	33 X 138 FT
THRUST	7,500,000 LBS
ENGINES	5 F-1
PROPELLANTS	LOX & RP-1
S-II	
SIZE	33 X 81 FT
THRUST	1,000,000 LBS
ENGINES	5 J-2
PROPELLANTS	LOX & LH_2
S-IVB	
SIZE	22 X 59 FT
THRUST	200,000 LBS
ENGINES	1 J-2
PROPELLANTS	LOX & LH_2
INSTRUMENT UNIT	
SIZE	22 X 3 FT
GUIDANCE SYSTEM	INERTIAL

Figure 1

ities. This report contains a statement of the problem, objective of the analysis, general approach taken in the analysis, description of the simulation model, (including inputs and outputs), and summary of the results achieved to date.

PROBLEM

The constraints of allowable launch azimuth, required earth orbit inclination, daylight at the lunar landing area, and daylight in the primary recovery area dictate a lunar launch opportunity consisting of an average of a single four-hour launch window on each of three consecutive days once in each lunar month (Fig 3). A requirement to update the spacecraft navigation program at discrete intervals may impose a further restriction. Additional constraints imposed by the handling of cryogenic propellants prevent a hold from one day to the next. A launch scrubbed after cryogenics are loaded for an attempt on the first day of a launch opportunity must be delayed at least until the third day of the launch opportunity. There are over 500 major events, subdivided into 20,000 subevents at KSC to prepare the Saturn V for launch. Completion of all events for successful launch in LOR launch window is far more difficult than any previous launch in the space program.

OBJECTIVE

In order to increase the probability of success, analytical studies are being conducted to predict the effectiveness of the Saturn V in the prelaunch period, to identify the major contributors to non-success, and to develop courses of action to reduce to a minimum the impact of the nonsuccess contributors. The measure of system effectiveness selected for this purpose is Launch Vehicle Availability (LVA) which is defined as the probability of the launch vehicle being ready to accomplish its mission during the assigned lunar launch window. Potential system improvements are evaluated to establish their impact on LVA. Recommendations are formulated to achieve the maximum increase in system effectiveness with a minimum commitment of additional resources. Implementation of the recommendations from this work results in increasing system effectiveness within the allowable constraints of schedule and cost. A secondary objective is cost and time saving by elimination of redundant testing and improvement of the testing sequence.

APPROACH

The approach adopted to satisfy these objectives is illustrated in Fig 4. This effort is in two distinct phases, baseline definition and systems optimization.

SATURN / APOLLO MISSION

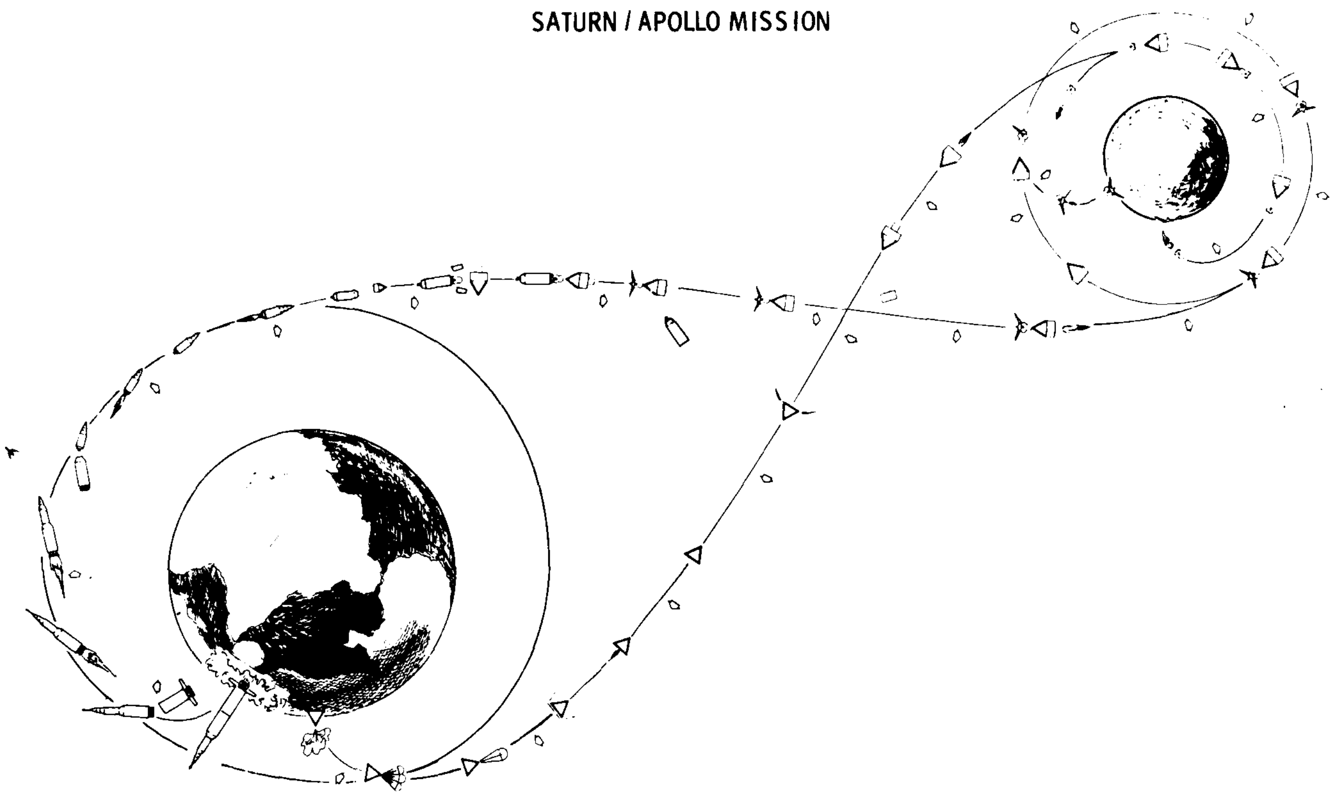


Figure 2

LOR LAUNCH OPPORTUNITIES - JANUARY 1967

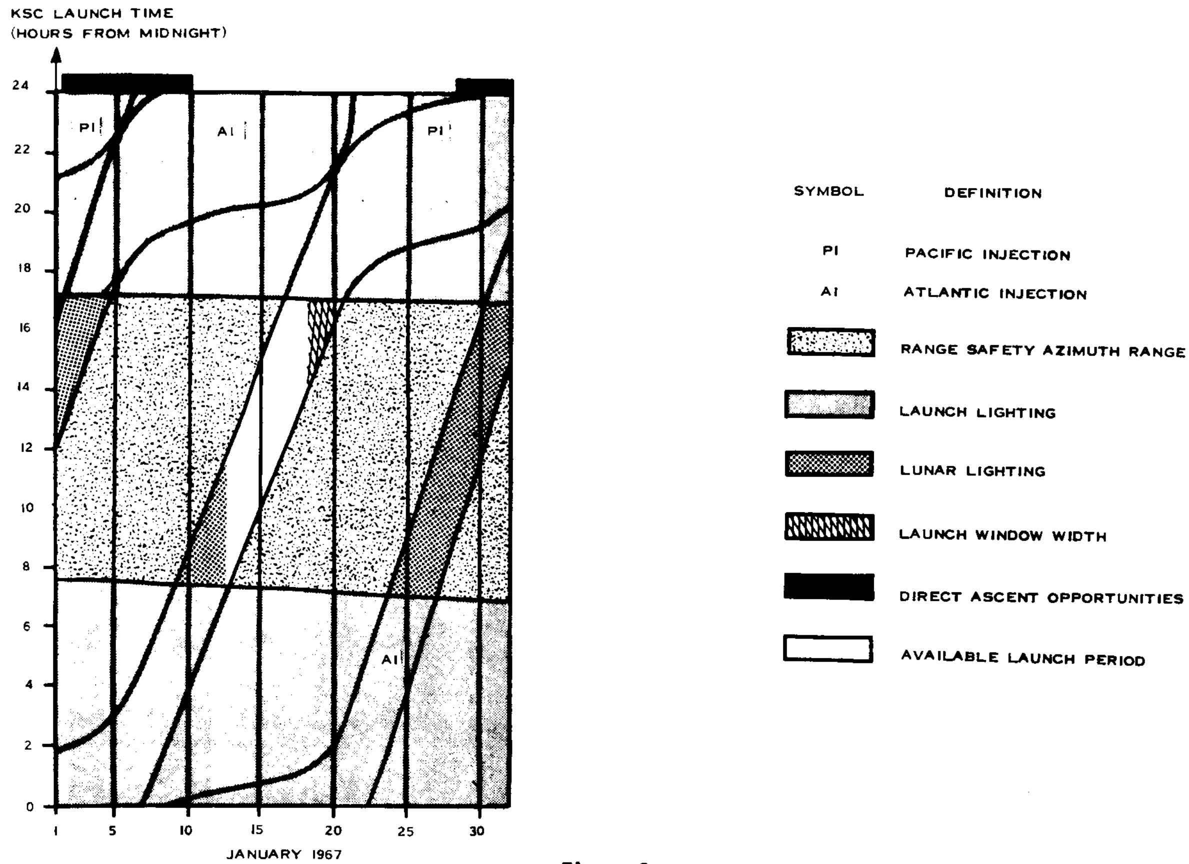


Figure 3

SATURN V PREFLIGHT SYSTEM ANALYSIS

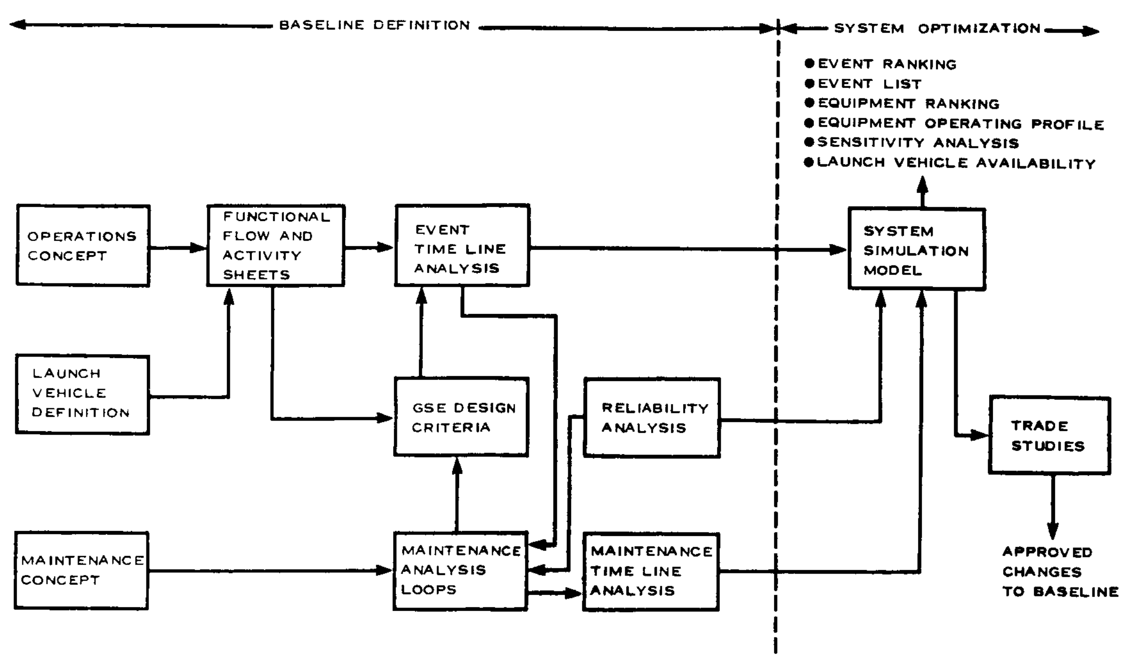


Figure 4

The baseline definition area is composed of operations, reliability, and maintenance analyses. It accepts the operations concept, the maintenance concept, and launch vehicle definition as fixed parameters. Functional requirements for processing the vehicle that must be satisfied by the ground support system are identified. The operations analysis (Functional Flow and Activity Sheets) develops requirements from those scheduled activities which are necessary to process the vehicle through assembly, checkout, and launch. The maintenance analysis develops requirements from the activities necessary to correct unscheduled faults occurring during the processing of the vehicle through the operations activities. These analyses define technical requirements and criteria which provide the basis for design specifications for Ground Support Equipment (GSE). These GSE technical requirements, together with the launch vehicle definition, and functional requirements for processing the vehicle, provide the basis for the time line analysis which organizes and constrains the parallel - series relationships of the processing activities.

The time line analysis provides the basic logic for simulating the assembly, test, and checkout of the Saturn V System. This effort, along with trade studies, comprises the second portion of the systems engineering effort. Systems optimization efforts are designed to integrate the operations and maintenance analysis into a dynamic system model to explore the interactions of the various parameters identified in the baseline data. Evaluations are made to identify problem areas, and trade studies are performed to choose the best alternate solutions. Based on these evaluations and studies, appropriate recommendations for equipment, procedure, or concept changes are made to increase the Saturn V System's effectiveness. The heart of the system optimization effort is a digital computer model that brings the system to life by simulating each event in vehicle processing, allowing equipment failures to occur as predicted by the reliability analysis, and repair as defined by the maintenance analysis.

MODEL DESCRIPTION

General

The Model consists of a data bank and a logic section (Fig 5). The data bank stores all input data and performs calculations which are independent of the sequential logic. The logic section contains the sequential logic (sequence of events, constraints between events, etc.) and the program for compiling results.

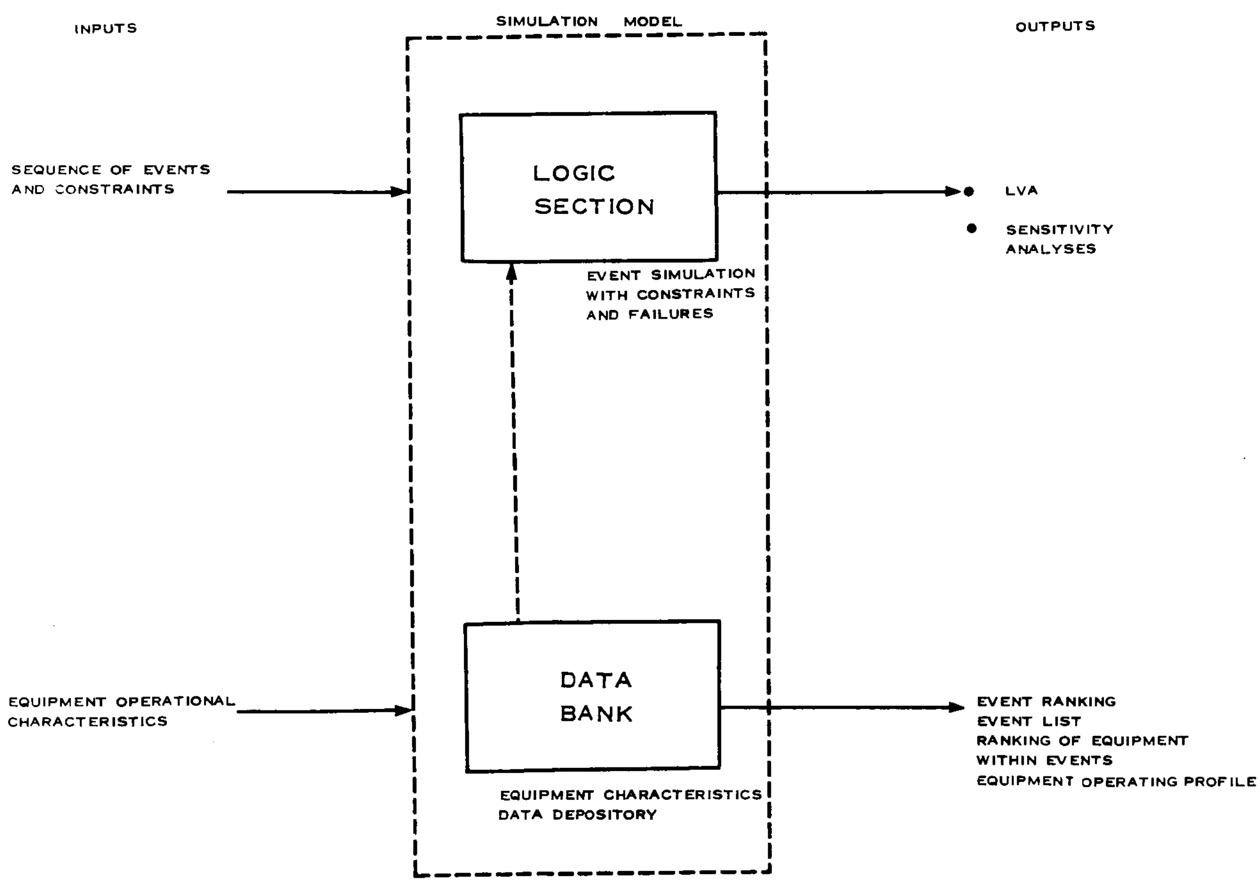


Figure 5

The model has been designed using the Boeing Modeling Technique (BMT). Since no existing technique was adequate to handle the problem, BMT was developed to provide a more powerful simulation language. The technique employs and takes advantage of three basic computer languages, General Purpose System Simulator (GPSS), Fortran, and COBOL, allowing engineers with a knowledge of the system to design the model without having formal training in programming. Fortran is used to perform basic calculations efficiently and Cobol offers the advantage of compiling data into comprehensive reports.

A major output of the model is launch vehicle availability. It is produced by simulating a series of launch attempts. Each attempt results in either a success (the launch vehicle is ready during the scheduled lunar window) or a failure. The ratio of success to attempts over a large number of trials is termed the Launch Vehicle Availability (LVA). The other outputs are used to identify the major factors contributing to non-availability. These include ranking of equipment and events by failure contribution, by schedule delay, and various sensitivity analysis.

Inputs

Inputs to the model can be classified as operations data, reliability data, and maintenance data.

The primary operations data consists of an identification of all events (assembly steps, transportation functions, and major tests) that must take place in the vehicle processings Figure 6. The data also includes normal sequence and duration of these events, and the constraints on start, finish, or conduct of each event. This information is the basic sequential logic for simulation. Associated information is an identification of each equipment component that must operate during any portion of the event and the length of time that it operates during the normal completion of the event. These inputs are developed from a detailed time line analysis of the entire sequence. The system hardware has been classified into 1100 vehicle components and 400 ground support equipment components.

The failure characteristics for each equipment component are provided from the reliability analysis. The approach taken is to assign a generic failure rate for each piece of equipment and adjust it for the varied operating conditions in different events by use of an event oriented environmental adjustment factor matrix. The intent of this matrix is to show that a single item of equipment operates in a normal ambient environment in one event, at cryogenic temperatures during a second event, and in a high intensity acoustic environment in a third event, and consequently, substantially different failure rates in each case.

TIME BAR (TYPICAL)

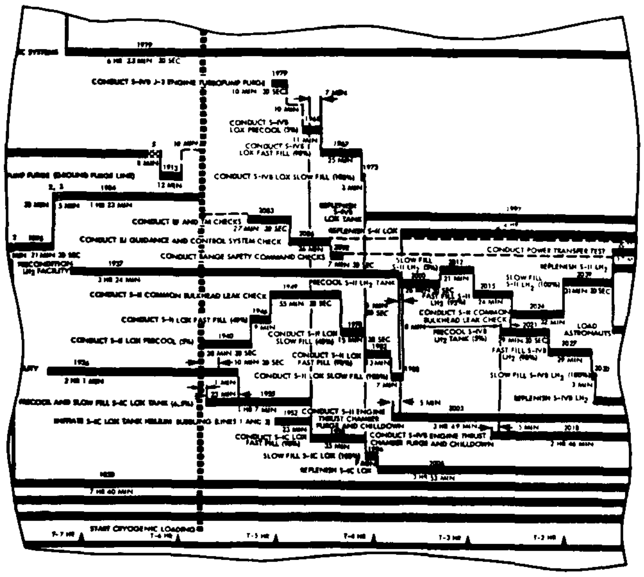


Figure 6

Maintenance data is provided from the maintenance analysis and consists of the repair and restore characteristics of the system. At each point in the operations sequence where there is an inspect, monitor, or verify subevent, the maintenance analysis assumes a failure or no-go condition, and develops the logic for fault isolation, access, remove and replace (or repair in place), verify, restore system, and retest as necessary. The estimated time to repair each component in each event is input directly to the model, with an identification of any previous events that must be repeated because of the equipment failure and repair.

A useful feature of the input procedure is that the appropriate model outputs are provided directly to the engineers performing the operation, reliability, and maintenance analyses, and they use these printouts as working documents in support of their other responsibilities. This input data is compiled in the event list, (Fig. 7). To input additional data or correct existing data, the engineer fills out a computer input sheet that goes directly to keypunch without interpretation or screening by an operations research man or computer programmer. This approach is highly successful because it places the full responsibility for data quantity and quality directly on the working engineer, and simplifies his problem of correcting any errors that occur.

A data element is defined as a useful item of information, such as an equipment name, an operating time, or a repair time. The Data Bank contains approximately 500,000 data elements which a continually being revised and upgraded as better information becomes available.

For instance, a significant portion of the reliability analysis consists of screening all failure reports and operating logs from the major test sites to re-evaluate predicted failure rates on the basis of actual field experience. The current revision rate is approximately 100,000 data elements monthly. This approach to data collection allows preliminary estimates during the earlier phases of the program where ballpark type results are adequate, followed by an orderly progression to more accurate results as this becomes important in later phases.

Calculations

The model simulates the processing of the vehicle event by event, through all of the events prescribed in the time bar, and in accordance with the constraints identified in the time bar. This logic is contained in the Logic Section of the model. When the processing of an event is simulated, the opportunity is provided for a failure to occur or not to occur in accordance with the probability of failure as calculated in the Data Bank for each item of equipment operating for the time associated with the normal completion of the event. If the failure occurs, the processing time for the event is increased by the time required to repair the failure. If the restoration of the system requires repetition of certain events, the opportunity is again provided for failure to occur in these events. Failure probability distributions and repair time probability distributions are calculated in the data bank and discrete values of these parameters are selected for each attempt by reference to a random number generator using the standard Monte Carlo technique. The sum of the time spent in each event or group of events is taken, reflecting the constraints and logic of the sequence. The total time to process is compared with the duration of the launch window. If the processing is successfully completed during the launch window, the launch attempt is successful. The ratio of the number of successes to total attempts over a large number of attempts is termed Launch Vehicle Availability.

During the execution of the simulation, the Logic Section interrogates the Data Bank to obtain:

1. Nominal event duration;
2. Failure or success decision;
3. Repair time;
4. Special routing instructions — restore events.

This arrangement allows frequent updating of the information in the data bank to reflect the most current and accurate information available. Most significant, these changes can be made without distrubing the Logic Section. Conversely, a minimum effort is required to make changes in the Logic Section.

EVENT LIST

EVENT 2093 CONDUCT S-IC, S-II AND S-IVB AUXILIARY HYDRAULIC SYSTEM OPN.

DURATION 6 HOURS 10 MINUTES LOCATION H

-PREREQUISITIES-

1. SUPPLY EXTERNAL POWER TO SPACE VEHICLE (EVENT 1911)

-POSTREQUISITES-

1. CONDUCT S-IVB LOX PRECOOL (5 PERCENT) (EVENT 1961)
2. PRECOOL AND SLOW FILL S-IC LOX TANK (6.5 PERCENT) (EVENT 1955)
3. CONDUCT S-II LOX PRECOOL (5 PERCENT) (EVENT 1940)

EQUIPMENT

EQUIPMENT CODE NUMBER	EQUIPMENT NOMENCLATURE	CTR	EQUIP TYPE	QUAN	OP HRS	TIME MIN	S7 HRS	TIME MIN	LAMBDA GENER	(X10-6) ADJUS	K	RE HRS	TIME MIN
304A	S-IC ENGINE HYDRAULIC SYS 4-WAY SOLENOID VLV ASSY	M	V	5	06	08	6	10	16	966	12	0	00
304B	S-IC ENGINE HYDRAULIC CHECKOUT VALVE	M	V	5	06	08	6	10	4	276	12	0	00
304E	S-IC ENGINE HYD SYS SERVO VALVE AND ACTUATOR (PITCH)	M	V	4	06	08	6	10	35	1718	12	0	00
304F	S-IC ENGINE HYD SYS SERVO VALVE AND ACTUATOR (YAW)	M	V	4	06	08	6	10	35	1718	12	0	00
306C 1	S-IC PCM DDAS ASSEMBLY	M	S	1	06	10	6	10	1,063	3504	8	5	30
307B	S-IC MULTIPLEXERS	M	S	3	06	10	6	10	1,037	24888	8	2	30
307C	S-IC SIGNAL CONDITIONERS	M	V	16	06	10	6	10	6	876	8	10	30
307D 3	S-IC TEMPERATURE TRANSDUCERS	M	V	8	06	10	6	10	30	480	2	0	00
307D 4	S-IC PRESSURE TRANSDUCERS	M	V	18	06	10	6	10	35	7560	12	6	05
309C	S-IC POWER MEASURING SUPPLIES	M	V	1	06	10	6	10	3	90	24	11	20
318B	S-II ENGINE AUXILIARY HYDRAULIC PUMP	M	V	4	06	10	6	10	9	432	12	38	00
318C	S-II ENGINE SERVO-ACTUATORS	M	V	8	06	10	6	10	35	6873	24	59	25
318D	S-II ENGINE ACCUMULATOR-RESERVOIR (ARMA)	M	V	4	06	10	6	10	26	2566	24	53	45
318E	S-II ENGINE HYDRAULICS HYD PUMP MOTOR THERMAL SWITCH	M	V	4	06	10	6	10	0	15	24	46	35
318F	S-II ENGINE HYDRAULICS MAIN HYD PUMP TEMP XDUCER	M	V	4	06	10	6	10	30	960	8	16	00
318G	S-II ENGINE HYDRAULICS TOTAL CIRCULATION BYPASS VALVE	M	V	4	06	10	6	10	5	547	24	16	00
318H	S-II ENGINE HYDRAULICS RESERVOIR THERMAL SWITCH	M	V	4	06	10	6	10	0	15	24	15	45
318I	S-II ENGINE HYDRAULICS ACCUMULATOR LOCKUP VALVES	M	V	4	06	04	0	04	5	547	24	55	00
320C 1	S-II PCM DDAS ASSY	M	S	1	06	10	6	10	1,063	8504	8	5	30
321B	MULTIPLEXERS	M	S	4	06	10	6	10	1,037	33184	8	2	30
321D 5	S-II PRESSURE XDUCERS	M	V	8	06	10	6	10	52	5011	12	4	30
323D	S-II POWER MEASURING SUPPLIES	M	V	1	06	10	6	10	3	90	24	11	20
333B	S-IVB AUX HYDRAULIC PUMP	M	V	1	06	10	6	10	53	1273	24	3	30
333C	S-IVB HYDRAULIC SERVO-ACTUATORS	M	V	2	06	10	6	10	35	1718	24	4	00
333D	S-IVB HYDRAULIC ACCUMULATOR-RESERVOIR (ARMA)	M	V	1	06	10	6	10	19	477	24	1	45
333E	S-IVB HYDRAULICS RESERVOIR OIL TEMPERATURE SWITCH	M	V	1	06	10	6	10	0	1	24	1	45

03/20/66 EVENT LIST - VOLUME III

Figure 7

The intent is not to discuss the details of the computer/program mechanics but to present the fundamentals of the model. Consequently, the manner in which decision rules for failures are formulated, repair times are generated, and restore events are determined will be discussed.

Event Simulation

It is assumed that the frequency distribution of failures will follow the Poisson's Probability Law. The frequency of failure is dependent upon the failure rate of the equipment operating within the event, its operating time, and the events duration, each of which is input to the Data Bank.

When an event is simulated (Fig 8) a decision is made on whether or not a failure will occur and if so what the time to failure (T_F) is. The decision is made by evaluating equation (1) for T_F by substituting for X a random number on the interval 0, 1. The equation is derived from the Poisson's Probability law where the probability of exactly P_j failures during time T is $\frac{(\Lambda T)^j e^{-\Lambda T}}{j!}$ (1)

$$T_F = \frac{1}{\Lambda} \ln (X)$$

$$\Lambda = \frac{\Sigma \lambda_i t_i}{T}$$

λ_i = failure rate of the ith equipment item in the event.

t_i = operating time of the ith equipment item in the event.

T = Event duration.

If the T_F is greater than the event duration T, the event is successful and the processing continues providing all constraints have been satisfied. If T_F is equal to or less than T, a failure occurs. A repair time is then determined by picking a value from a repair time histogram for the event, see Figure 9. The repair time selected is then recorded.

EVENT SIMULATION

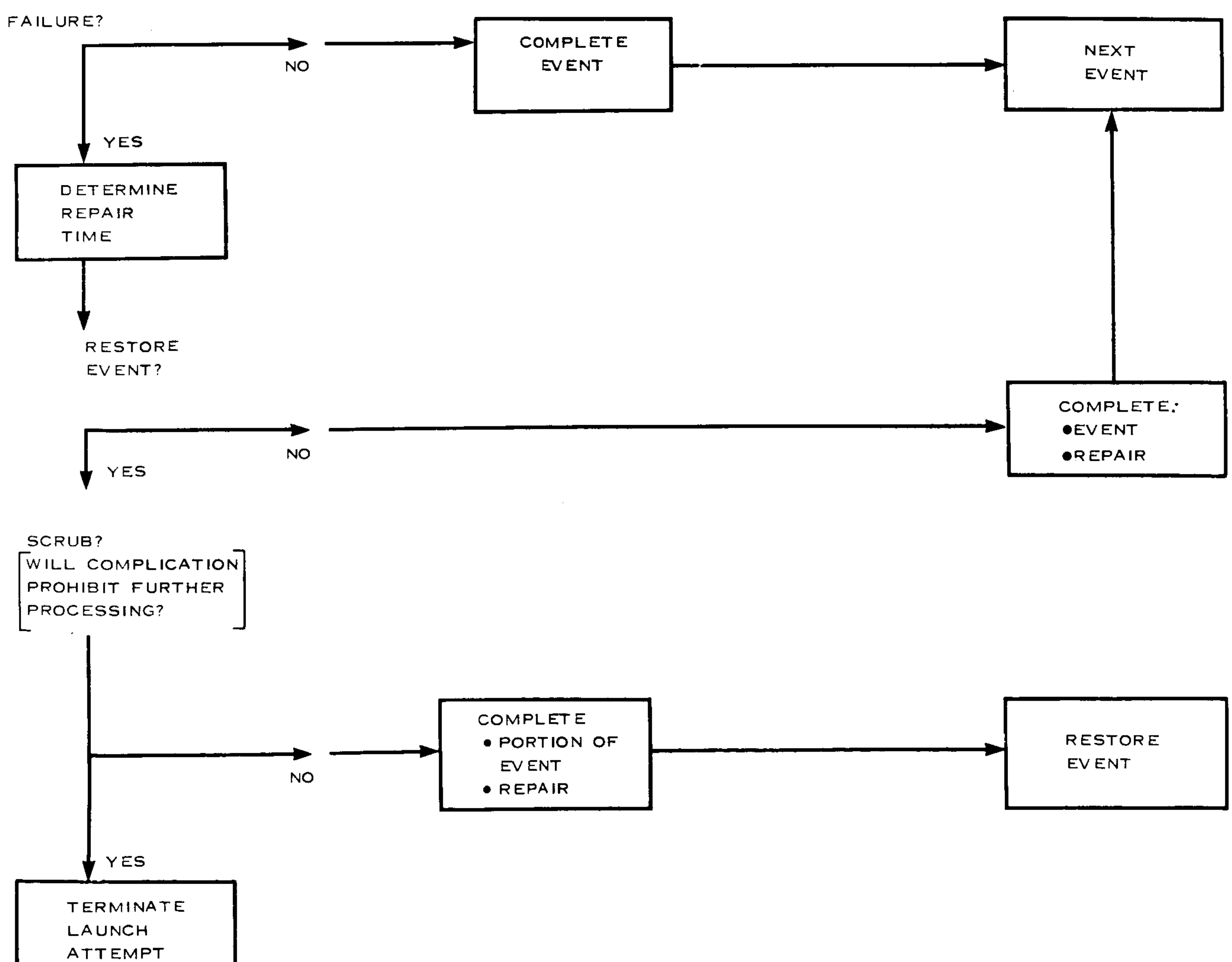


Figure 8

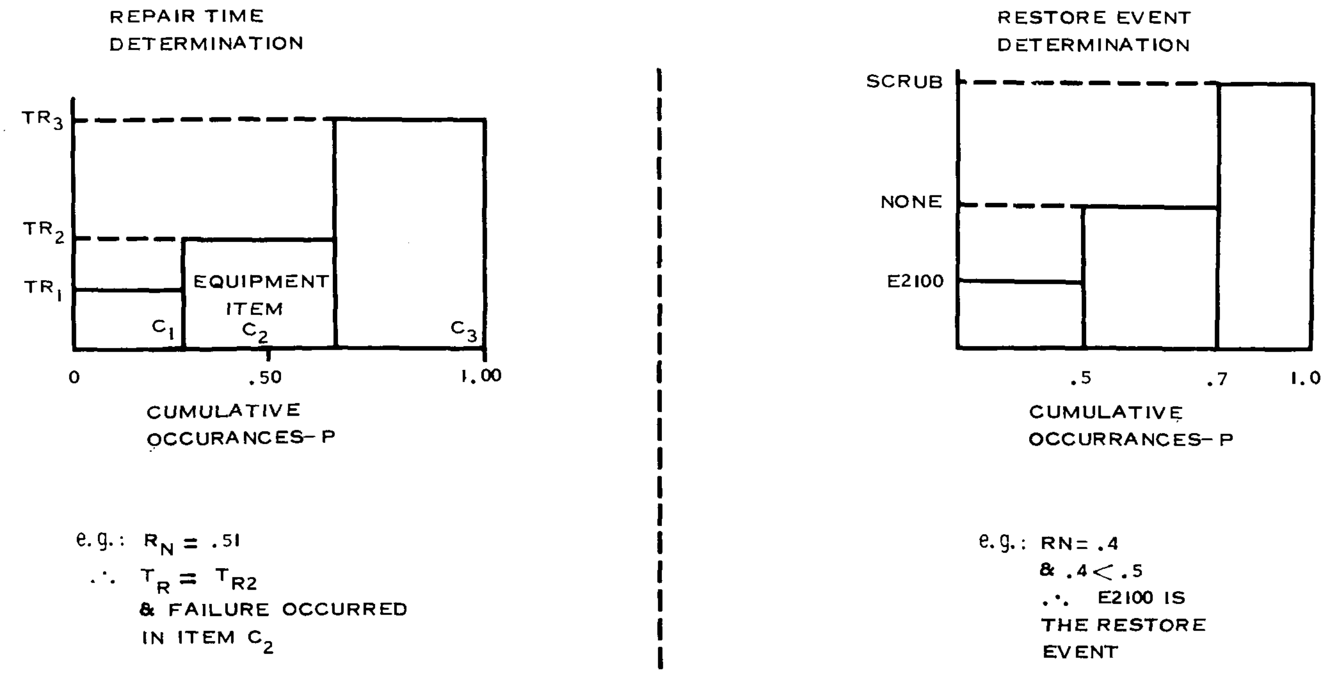


Figure 9

The next step is to determine if any events must be repeat ed; and if so, what the restore event is. The procedure is the same as that described for repair time and T is also illustrated in Figure 9. If there is no restore event, then the event processing is completed and the repair time added to the nominal processing time. If a scrub is indicated, then the launch attempt is terminated. Assuming that a series of events must be repeated, then when the time to failure (T_F) is reached, the processing is interrupted, repair time added, and then the program begins processing again at the restore event specified.

Outputs

The outputs obtained from the model are; Launch Vehicle Availability, Event Ranking; Equipment Ranking; Sensitivity Analyses; Events Lists; and, Equipment Operating Profile.

Launch Vehicle Availability is discussed on page 12.

Event Ranking in order of increasing probability of success are shown in Fig. 10. This is the top ten events out of the 500 events required to process the vehicle for launch. The Model ranks the events by considering the equipment required to perform the event, its failure characteristics, and operating time within each event. This data is a routine printout of the Data Bank.

Equipment Rankings are illustrated in Fig. 11. These printouts show the equipment associated with each event and the percent contribution to the probability of success that each item of equipment makes.

Sensitivity Analysis results are shown in Fig. 12 for changes in reliability and maintainability. These curves are obtained by exercising the model with arbitrarily changed reliability and maintainability characteristics.

The Equipment Operating Profile gives the total operating time for each item of equipment in support of each event and the total operating time in support of all the events. Fig. 13 shows a printout of the operating profile from the model.

INTERPRETATION OF OUTPUTS

As stated previously, the objectives of this effort are to develop an understanding of the Saturn V System, to identify major contributors to non-success and to establish courses of action to improve the non-success contributors. To satisfy this objective, the outputs from the Model must be interpreted. The most significant output is Launch Vehicle Availability. It is the primary measure of system effectivensss and its absolute value provides the best available understanding of whether or not the Saturn V will do its job during the prelaunch phase. The change in Launch Vehicle Availability when changes in parameters of the system are exercised in the Model provides a measure of the effectiveness of each proposed change. The remaining outputs are employed primarily to identify which elements of the system should be considered first in order to identify problems and maximize the pay-off from the corrective action. The events in the upper portion of the event ranking (Figure 10), for instance, are those in which the largest number of failures occur. Each event that is high in this ranking may not

EVENT RANKING (CRYOGENIC LOAD TO LIFTOFF)

SA-501

	EVENT	EVENT NAME	FORMER RANKING	DURATION HRS	DURATION MIN	PROBABILITY OF SUCCESS	
1.	2093	CONDUCT S-IC, S-II AND S-IVB AUXILIARY HYDRAULIC SYSTEM OPN	2	06	10	0.89	0.85) *
2.	8503	OPERATE DDAS (CRYOGENIC LOAD TO T-3 MIN)	1	07	08	0.93	(0.36) *
3.	8501	OPERATE RCA-110A COMPUTERS DURING TERMINAL COUNTDOWN	4	07	08	0.94	
4.	1526	ENVIRONMENTAL CONTROL TO SPACE VHEICLE	(NEW)	07	08	0.96	
5.	1997	REPLENISH S-IVB LOX TANK	7	04	09	0.97	
6.	1949	CONDUCT S-II COMMON BULKHEAD LEAK CHECK	8	00	56	0.98	
7.	2107	PRESSURIZE S-IVB LOX TANK COLD HELIUM SUPPLY SPHERES	9	00	46	0.98	
8.	2027	FAST FILL S-IVB LH_2 93 PERCENT	(NEW)	00	29	0.98	
9.	1955	PRECOOL AND SLOW FILL S-IC LOX TANK 6.5 PERCENT	(NEW)	01	07	0.98	
10.	1967	CONDUCT S-IVB FAST FILL 98 PERCENT	(NEW)	00	25	0.99	

*FORMER PROBABILITY OF SUCCESS

Figure 10

EQUIPMENT RANKING

(IN EVENT 2093)

ITEM	NOMENCLATURE	λ_g	t	K	N	$\lambda_g tKN$		
321B	S-II MULTIPLEXERS	.001037	6.10	8	4	.205		
307B	S-IC MULTIPLEXERS	.001037	6.10	8	3	.153		
336B	S-IVB MULTIPLEXERS	.001037	6.10	8	2	.102	60%	
306C	S-IC PCM/DDAS	.001063	6.10	8	1	.052		
320C	S-II PCM/DDAS	.001063	6.10	8	1	.052		
335C	S-IVB PCM/DDAS	.001063	6.10	8	1	.052		
307D4	S-IC PRESS. XDUCERS	.000035	6.10	12	18	.047		
318C	S-II ENG. SERVO ACTUATORS	.000035	6.10	24	8	.042		
321D	S-II PRESS. XDUCERS	.000052	6.10	12	8	.031		
500A	S-IC DDAS SYSTEM M/L	.005068	6.10	2	1	.025		89%
500B	S-II DDAS SYSTEM M/L	.005068	6.10	2	1	.025		
500C	S-IVB DDAS SYSTEM M/L	.005068	6.10	2	1	.025		
622A	S-IC DDAS SYSTEM LCC	.005088	6.10	2	1	.025		
622B	S-II DDAS SYSTEM LCC	.005088	6.10	2	1	.025		
622C	S-IVB DDAS SYSTEM LCC	.005088	6.10	2	1	.025		

60 ADDITIONAL ITEMS

λ_g = GENERIC FAILURE RATE
t = OPERATING TIME
K = ENVIRONMENTAL ADJUSTMENT FACTOR
N = QUANTITY

Figure 11

AVAILABILITY AS A FUNCTION OF SYSTEM IMPROVEMENT

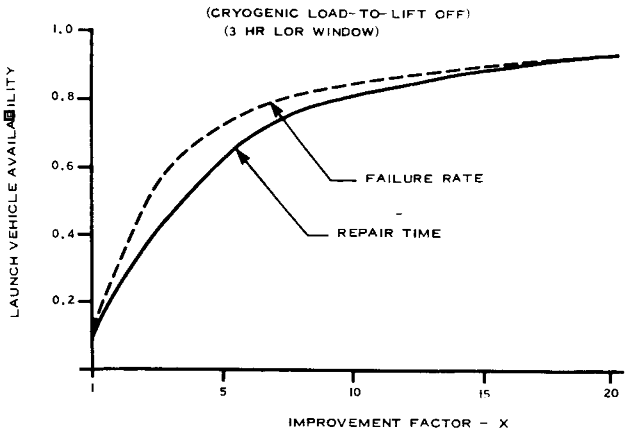
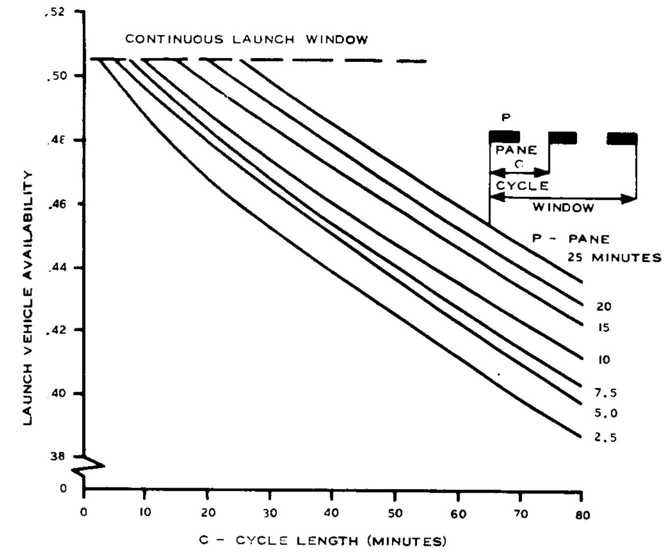


Figure 12

necessarily contain a real problem, but by examination of the detailed parameters of these events, one is most likely to identify the real problems. Similarly, the equipment is ranked both by successful probability and by expected schedule delay. The real trouble-makers in the system are expected to be high in one or both of these rankings.

Sensitivity analyses indicate how the system reacts to changes in its parameters. By these analyses the variation in system effectiveness is assessed as design

EFFECT OF WINDOW PANES ON LVA



P PANE: A DISCRETE PERIOD OF TIME IN WHICH THE SPACE VEHICLE MAY BE LAUNCHED DURING THE LAUNCH WINDOW

C CYCLE: THE TIME PERIOD FROM THE START OF ONE PANE UNTIL THE START OF THE NEXT PANE.

Figure 14

parameters of the equipment are changed, the events are resequenced,or tests are added to or deleted from the sequence. Fig. 12 shows a comparison of the results of making major improvements in the reliability or the maintainability of the system. Fig. 14 shows the impact on Launch Vehicle Availability if the allowable

EQUIPMENT OPERATING PROFILE

EQUIPMENT 328E S-IVB LH2 TANK VENT DIRECTIONAL CONTROL VALVE LAMBDA 4.50 X 10-6

EVENT	EVENT TITLE	OP TIME HRS MIN	LOC	QUAN
0957	CONDUCT FUNCT AND LEAK TEST. S-IVB FUEL SYSTEM	04	A	1
1563	CONDUCT LIMITED VEHICLE PROPULSION SYSTEMS STATUS CHECKS	00	D	1
1605	CONDUCT S-IVB FUEL SYSTEM VERIFICATION TEST	2 32	D	1
1707	SLOW FILL S-IVB LH2 TANK (5 PERCENT)	30	E	1
1713	FAST FILL S-IVB LH2 (98 PERCENT)	29	E	1
1719	SLOW FILL S-IVB LH2 (100 PERCENT)	03	E	1
1725	REPLENISH S-IVB LH2	42	F	1
1743	DETANK S-IVB LH2 TANK	2 02	E	1
2021	PRECOOL S-IVB LH2 TANK 5 PERCENT	28	H	1
2027	FAST FILL S-IVB LH2 (98)	29	H	1
2030	SLOW FILL S-IVB LH2 100 PERCENT	03	H	1
2036	REPLENISH S-IVB LH2	1 39	H	1
2122	CONDUCT S-IVB FUEL AND OXIDIZER PRESS DURING AUTO COUNTDOWN	3	H	1

LOCATION	3LK		A		B		C		D		E		F		G		H		I	
	HRS	MIN	HRS	MIN	HRS	MIN	HRS	MIN	HRS	MIN	HRS	MIN	HRS	MIN	HRS	MIN	HRS	MIN	HRS	MIN
OPERATING TIME									2	32.0	3	30.5					2	36.0		

TOTAL OPERATING TIME IS 8 HOURS AND 38.5 MINUTES

A	ON DOCK TO MATE	D	ON PAD TO WET TANK TEST	G	REMOVE MSS TO START CRYOGENIC LOAD
B	MATE TO EXIT VAB	E	DURING WET TANK TEST	H	CYROGENIC LOAD TO IGNITION
C	EXIT VAB TO MATE TO PAD	F	END WET TANK TEST TO REMOVE MSS	I	IGNITION TO LIFT OFF

EQUIPMENT OPERATING PROFILE DATA 1 APRIL 1966 PAGE 124

Figure 13

time to launch within the launch window is further restricted by the need to update the navigation program. By developing a complete understanding of the system behavior as a result of scrutiny of sensitivity analyses, the system analyst gains an understanding of where resources should be concentrated to acquire the most cost-effective results.

When the areas for improvement have been identified, the trade studies are initiated to develop a alternate solution. The trade studies develop potential alternate courses to improve the situation. These are evaluated considering appropriate factors such as the change in system effectiveness, technical feasibility, schedule feasibility, cost, etc. Based on these evaluations, recommendations are formulated and forwarded to the customer. If he decides to implement a recommendation the appropriate revisions are made to the system baseline and Model.

RESULTS

Results obtained from the analyses described in this report include: the identification of requirements for the ground support system; verification that the total system design satisfies all the functional requirements for the prelaunch phase; focusing of management attention on significant problems that could become program stoppers without this attention; recommendations for system improvement that could save over 7 million dollars per launch, and continuing assessment of system effectiveness in the prelaunch phase.

Support system requirements identified by the operations and maintenance analysis include the detailed design requirements for ground support equipment. Existing equipment designs have been assessed against these requirements resulting in the need to buy 40 additional items of ground support equipment and modify six. More important, the analyses verify that the equipment purchased and modified will satisfy the operational requirements for processing the vehicle.

Another significant achievement is the identification of several problems that could have become program stoppers, had not vigorous management action been taken. These problems have been brought to the attention of top NASA program management personnel in monthly briefings. A top-10 problem list has been maintained in the program control center, and the program manager has directed his personal attention to these top-10 problems. Since no one likes to be in the spotlight for having the top program problem, vigorous action occurs at all levels in an effort to resolve it. In some cases the solutions become apparent through the analysis activity, but more often, the analysis and problem identification simply acted as a catalyst to make vigorous management action take place.

Improvements are the result of a trade-off of parameters such as equipment reliability, equipment maintainability, cost, safety, operational concepts, maintenance concepts, processing time and launch window constraints. The balance of these trade-off's will be the total system improvement that is feasible within the boundaries of program constraints, such as budget and launch schedules.

A summary of the trade studies that have been performed are:

<u>A Report on Ambient Helium Sphere Pressurization</u> recommended that helium spheres should not be vented before transporting the vehicle to the Pad. It was concluded that this procedure would save helium, test time, and would eliminate a possible hazard to personnel.

<u>An Investigation Into The S-II Bulkhead Ultrasonic Test</u> recommended elimination of the operational requirement for an ultrasonic check of the S-II Stage common bulkhead during Low Bay operations.

<u>A Review Of Saturn V Propellant Loading Sequence</u> recommended a change in the sequence of events to reduce countdown time.

<u>Low Bay Versus High Bay Propellant Tank Leak Test</u> recommended performing the S-II and S-IVB propellant tank leak tests in parallel in Low Bay instead of in series in High Bay.

<u>Abbreviated Wet Tanking Test</u> recommended conducting partial instead of 100 percent loading of propellants during wet tanking, thus saving loading time and propellants and concomitant detanking time.

<u>Resequencing of Events - LES Installation</u> recommended installing the flight Launch Escape System (LES) in High Bay instead of on the Pad, because this provides a complete vehicle during several tests, reduces personnel hazard on the Pad, and saves critical Pad time.

<u>Parallel Versus Series Sequencing Of Spacecraft And Launch Vehicle Events</u> recommended sequencing certain spacecraft and launch vehicle events in parallel instead of in series in High Bay.

<u>Redundant Space Vehicle Testing In High Bay</u> recommended the elimination of several redundant tests and the resequencing of other tests.

<u>F-1 Engine Thermal Insulation</u> investigated the feasibility of reducing the installation time and complexity of the thermal blanket installation. A metal shield was recommended that would replace the current cocoon over the engine and would result in a reduction of installation time from 1,120 manhours to approximately 840 manhours.

<u>Mating Of The Instrument Unit To The S-IVB Stage In Low Bay</u> investigated the feasibility of mating the IU and S-IVB Stage in Low Bay instead of in High Bay. The use of a proposed adapter ring between the S-IVB Forward Protective Ring, would result in significant reductions in processing time and consequent cost savings can be realized. Figure 15 is a summary of the results of these trade studies and shows the resulting changes in parameters.

The prediction of Launch Vehicle Availability has changed significantly since January of 1966, as illustrated in Figure 16. The prediction now is for the SA-501 Vehicle with a typical lunar orbital rendezvous mission launch window constraint.

The change in Launch Vehicle Availability prediction is the cumulative effort of implementing trade study recommendations, providing additional and modified GSE, and elimination of program stoppers.

SATURN V LAUNCH VEHICLE AVAILABILITY (LVA) PREDICTIONS
FOR 3 HOUR LAUNCH WINDOW
CRYOGENIC LOADING THROUGH LIFTOFF

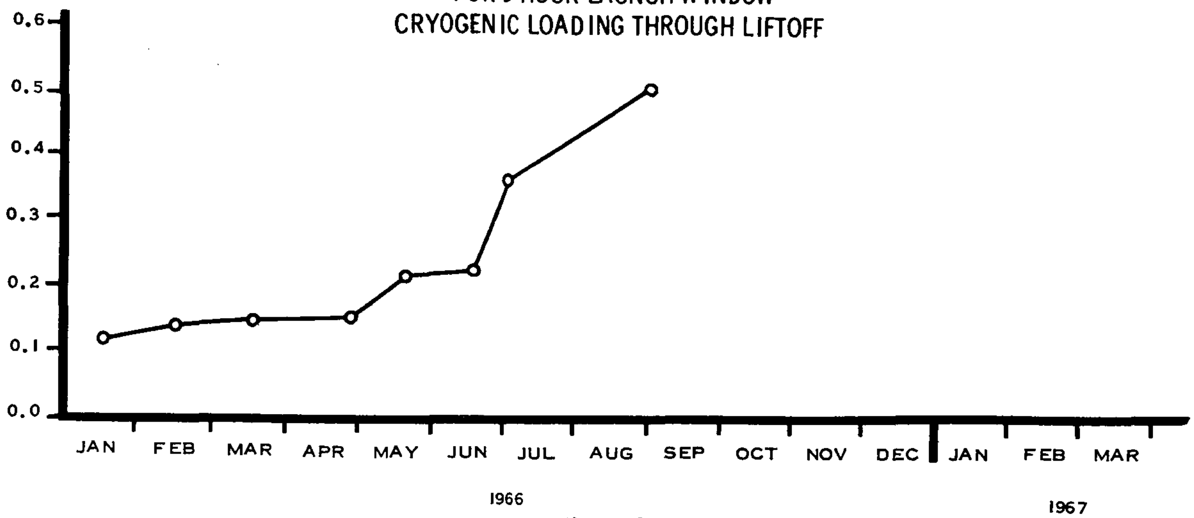


Figure 15

SA-501 TRADE STUDY SUMMARY

TRADE STUDY	TIME		COST ($)	RELIA-BILITY	MAINTAIN-ABILITY	AVAILA-BILITY	SAFETY
	HRS	MIN					
AMBIENT HELIUM SPHERE PRESSURIZATION	-20	00	-50,000	→	→	↑	↑
S-II COMMON BULKHEAD ULTRASONIC TEST	-559	30	-6,714,000	→	→	↑	↑
PROPELLANT LOADING SEQUENCE	-0	29	-5,800	→	→	↑	→
LOW BAY VS. HIGH BAY PROPELLANT TANK LEAK TEST	-17	57	-215,000	→	↑	↑	↑
ABBREVIATED WET TANKING TEST	-6	19	-84,000	→	↓	↑	↑
RESEQUENCING OF EVENTS. LES INSTALLATION	+3	44	+39,000	→	→	→	↑
PARALLEL VS. SERIES SEQUENCING OF SPACECRAFT AND LAUNCH VEHICLE EVENTS	-7	19	-84,000	→	→	↑	→
REDUNDANT SPACE VEHICLE TESTING IN HIGH BAY	-8	19	-100,000	↑	↑	↑	↑
F-1 ENGINE THERMAL INSULATION	-10	00	-3,000	→	↑	↑	↑
MATING OF THE IU TO THE S-IVB IN LOWBAY	-12	47	-123,000	↑	↑	↑	↑
TOTAL	-637	36	-7,379,000	→	↑	↑	↑

Figure 16